BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 149

Contribution from the Bureau of Soils, Milton Whitney, Chief.
December 11, 1914.

THE USE OF RADIOACTIVE SUBSTANCES AS FERTILIZERS.

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INTRODUCTION.

A fertilizer may be conveniently defined as any commercial material which, when added to a soil that has been brought into suitable condition for the growth of plants, produces an increased yield in crop production. In producing this result a fertilizer may act in various ways, bringing about an improvement in the chemical, physical, or biological condition of the soil, and generally in all of these. An improvement in all these three classes of soil conditions may also be brought about by other farm operations, as by tillage, green manuring, and the rotation of crops. To what extent these latter operations should be supplemented, or even in a measure replaced, by the use of fertilizers so as to lead to the most profitable returns, is a matter which has given rise to a great deal of controversy, and there still remain considerable differences of opinion on the subject. This is due in a large measure to the fact that the results obtained from experiments carried on locally and under special conditions of farming are often quoted as applying to the whole country, and to conditions of farming of an entirely different type. It is quite evident, however, that any set rules governing the use of fertilizers in farm practice are only applicable when all conditions of soil fertility, climate, cultivation, and crop production are about the same. Fertilizers must therefore be used differently under different conditions, and it is universally admitted that when intelligently applied, where the conditions warrant it, the use of the proper fertilizer brings profitable returns.

A great many forms of fertilizers are used, but all those commercial products which are recognized as of value in the fertilizer trade have the common feature of containing one or more of the

Note.—This bulletin discusses the fertilizer value of radioactive materials; it is suitable for distribution in any part of the United States.

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elements—nitrogen, potassium, phosphorus, and calcium. These elements are therefore spoken of as fertilizing elements.

It is further recognized that in a very general way the value of a material is proportional to the percentage of the fertilizing constituent or constituents present in soluble form. Because of its wide distribution, calcium can usually be obtained locally, and consequently it does not enter into the fertilizer trade in the same sense as the other fertilizing elements. To each of the three remaining elements is given by common consent and as a trade practice a definite value per unit, which varies with the form in which the element occurs; the price set on a standard fertilizer, while thus in a sense an arbitrary one, is nevertheless determined in a scientific way by multiplying the percentages of the constituents present by their prices per unit and adding the products.

If nitrogen, potash, and phosphoric acid are absent, the fertilizing value of the material as calculated in this way will be zero; and no material, with the exception of certain calcium compounds, as lime and gypsum, that does not contain one or more of the constituents referred to is recognized at present by agricultural scientists as having commercial value as a fertilizing agent for general farming.

Notwithstanding these facts there have frequently been placed on the market from time to time various so-called fertilizers which contain little or none of the recognized fertilizing elements even in an insoluble form. As a rule these materials consist simply of ground rock, usually of volcanic origin, from various sources, and for which an arbitrary price is asked out of all proportion to the value of the small amount of the fertilizing elements which may be present. Some of these materials, although exploited to quite an extent in the past, have later fallen into disfavor and are now no longer used by anyone, but others of more recent development are still being placed on the market under different trade names. One of these new materials, which is known as "radioactive manure," consists of low-grade uranium-radium ores or ores from which the uranium has been extracted, and it is claimed to bring about by virtue of its radioactivity phenomenal increase in crop yields when mixed with barnyard manure and applied to the soil. Within the past few years the use of this material as a fertilizer has been quite extensively advertised in various parts of the world, and accounts have been given in various scientific publications of numerous results which have been obtained in pot and field tests using radioactive material from different sources.

The object of this bulletin is to give a review of these results and likewise an explanation of the property of radioactivity, in order that a conclusion may be reached as to the value of applying radioactive material to the soil.

PROPERTIES OF THE RADIO-ELEMENTS.

The properties of the radio-elements have been investigated by many of the leading scientists of the present day and have consequently been determined with a degree of exactness and completeness which perhaps has never before been equaled in any other branch of science in the same length of time.

The following points with regard to these properties may be enumerated as having bearing on the fertilizing value of radioactive material:

1. An element is said to be radioactive when it has the property of disintegrating or changing into another element. This property of radioactivity as exhibited by radium, which is the best known popularly of the radio-elements, is one which is inherent in the atom. No substance can be radioactive which does not contain an element which would be radioactive if separated from the substance, and, conversely, if a substance contains such an element, it must be radioactive. Some of the radio-elements, like the ordinary elements, do not give off any rays; others give off one kind of rays only; while still others give off two different rays, each of which may differ from the single radiation, thus making altogether three different kinds of rays. No inactive substance can be made radioactive by exposure to any of these rays. The activity of a given quantity of a radioactive element, like uranium or radium, remains unchanged in whatever chemical or physical state it may exist, whether combined in a soluble or insoluble compound, and whether or not it may be mixed with any substance or substances whatsoever. It therefore follows that its activity can not be intensified by mixing with barnyard manure, as is sometimes claimed.

2. Radium is a product of uranium and can not occur in nature in quantity exceeding the amount with which it is in equilibrium with uranium. For this reason the highest concentration of radium which can ever be found in any ore will amount to only one part of radium in 3,460,000 parts of ore. This quantity of radium is so small that if chemical tests alone had been applied neither radium nor any of its products could ever have been identified. There are physical tests, however, which are much more delicate than any chemical tests. Thus, when the spectroscopic test is applied to lithium, an element which according to chemical tests is of very limited distribution, it is found to be almost universally distributed, and in no spring water, for example, does the test fail to reveal its presence. The electroscopic test for radium is even much more delicate than the spectroscopic test just cited, and it thus happens that radium which occurs in soils, for example, in such minute quantities can nevertheless be identified in all soils. If the same delicate test could be applied to all the ordinary elements, it is universally admitted that they, too,

would be found in all soils[1] and in much larger amounts than radium, for the reason that they occur in nature in much larger quantities. The ordinary elements could not have been discovered if this were not the case. Most soils differ but little in their radium content, as must follow from the fact that almost all rocks[2] which do not contain uranium ores contain pretty much the same quantity of radium.

On an average the radium present in an acre-foot of soil amounts to about 3.6 milligrams.[3] The radium present in 1 ton of carnotite ore containing 2 per cent of uranium oxide (U_3O_8) amounts to 5 milligrams. To duplicate the amount of radium in an acre-foot of soil would therefore require about three-fourths of a ton of 2 per cent carnotite ore from which radium has not been extracted, and which brings about $80 a ton wholesale. It is thus quite evident that to increase the radium content of the soil to any great extent by the use of carnotite or any other radium ore is out of the question as an economic proposition.

The chemical properties exhibited by an element in combination depends on whether the element occurs in a soluble or insoluble form. Thus, the addition of a comparatively small amount of a soluble potash salt has a marked effect on the growth of plants, while the corresponding amount of an insoluble potash silicate would have little or no effect so long as it remained insoluble. As already explained, the property of radioactivity does not change in this way with the form of combination and a given weight of radium in the soil has exactly the same activity as the same weight of radium in any other form of combination that can be added. The argument, therefore, can not be advanced that the radium in radioactive manure is in a more active form than that already present in the soil.

3. When a preparation of radium which has been freed from its products is allowed to stand for a time, the products are again formed and finally reach a state of equilibrium with the radium. When this is the case, the material has its greatest activity, and any preparation which is allowed to stand for a time always consists of a mixture of radium and its products. The first of the products to be formed from radium is a gas called radium emanation. Since radium itself gives off rays, while radium emanation is a product of radium, the activity of radium emanation in equilibrium with its products must always be less than that of radium in equilibrium with its products. It therefore follows that no preparation of radium emanation can be obtained which is more active than the radium available.

When the radium emanation is removed from a preparation of radium, the total radiation evolved from the two sources remains the

[1] The presence of the rare earths and other rare elements in all soils examined has been demonstrated by W. O. Robinson of the Bureau of Soils. Bul. 122, U. S. Dept. Agr.

[2] Strutt, Proc. Roy. Soc. Lond., (A) 77, 472 (1906).

[3] Moore, J. Ind. Eng. Chem., 6, 373 (1914).

same as that given off from the preparation before the separation. The total radiation has thus not been either increased or decreased by the treatment, and as far as the use of the rays is concerned it must necessarily be just as expensive, although possibly at times more convenient, to treat plants with radium emanation as with the radiation from the equilibrium amount of radium.

THE INFLUENCE OF RADIOACTIVE RAYS ON PLANTS.

Every physical agent known when exceeding a certain minimum intensity is able to affect in a marked degree the germination of seeds and the growth of plants. It would therefore be expected that the rays from radioactive substances, when present in sufficient intensity, would likewise have an influence on plant growth. A great many experiments have been made along this line, and the literature on the subject is already very extensive. Unfortunately in many of the experiments which have been made, no mention is made of the amount of radioactive material used nor of the intensity of the radiations emitted by it. Consequently such experiments can not be duplicated by others, and the results reported are therefore of little value, for it could have been predicted that a very intense radiation would have an injurious effect on plant growth, while radiations of moderate intensity might exert a beneficial effect. Furthermore, owing to an insufficient knowledge of the properties of radioactive rays, many experiments have been carried out in such a way that the effects which were attributed to the rays could not possibly have been due to this influence.

The most extensive experiments in this field which have been described in this country were carried out by Gager[1] at the New York Botanical Garden. In one set of pot experiments a quantity of polonium (activity not given) inclosed in a sealed glass tube was inserted in the soil at the center of the pot, with the end containing the radioactive material about 10 millimeters below the surface. Twelve grains of wheat were then planted without soaking in the soil around the tube. Three other pots were also prepared in the same way with the same number of wheat grains; in one of the pots was placed a tube containing 10 milligrams of radium bromide of 1,800,000 activity; in another, a tube containing 10 milligrams of radium bromide of 1,500,000 activity, while the remaining pot was used as a control. On the fourth day measurements were made of the height of the seedlings, and it was found that the average growth was greatest in the pot containing the polonium and least in the control pot. It is known, however, that polonium gives off alpha rays only, and that these rays are so lacking in penetrating power that they could not

[1] Effects of the Rays of Radium on Plants, Memoirs of the N. Y. Botanical Garden, vol. 4 (1908).

have penetrated the walls of the glass tube[1] in which the polonium was contained, much less could they have penetrated the intervening soil which separated the tube from the planted seeds. If the experiments were carried out as described, the seeds in the pot containing the polonium tube must have been as free from any radioactive influence as those in the control pot, and the marked increase noted in the growth of the seedlings in this pot could not have been due to the presence of the polonium tube as claimed by the author, but must be attributed to some other influence.

From the way in which other experiments were carried out it seems reasonable to suppose that other results were likewise incorrectly attributed to radioactive influence. Thus it was concluded "that freshly fallen rain water tends to retard the growth of roots of beans (*Lupinus albus*) and that the effect is due to the radioactivity of the water."[2] It was further observed from other experiments that "the growth in length of radicles of *Lupinus albus* is uniformly accelerated in an atmosphere containing radium emanation."[3] The intensity of the radiation was not given in either case, but it was indicated, and it is undoubtedly a fact, that the intensity of the radiation in the latter experiment was much greater than in the former. It would thus seem that as measured by the growth that takes place without any radioactive influence, a weak radiation retards, while a stronger radiation stimulates the growth of certain seedlings. This is contrary to experience and to the general conclusion reached by the author that "the rays of radium act as a stimulus to protoplasm. Retardation of growth following an exposure to the rays is an expression of overstimulation. Acceleration of growth indicates stimulation between a minimum and an optimum point."

Experiments were also described in which seeds and seedlings were exposed in a 6-inch pot to the radiation from 10 milligrams of radium bromide of activity 1,800,000. A preparation of 0.5 gram of radium bromide of activity 10,000 was also used. Both retarding and stimulating effects were observed, depending on the seedlings used and the conditions of the experiments. It would be expected that with a radiation of the intensity given by these preparations a marked effect would result, as was observed. The experiments are thus of scientific interest, but they do not give any indication that radium can be of any practical value in general farming. To duplicate the experiments on a large scale would require a quantity of radium which is not available.

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[1] In this connection the author himself states: "I am unable to explain how physiological effects can be obtained with radio-tellurium [polonium] in a sealed glass tube, for this substance gives off only α rays, and these are not thought to be able to pass through the glass walls of the tube. The results, however, were constant and decided, leaving not the slightest doubt as to the physiological efficacy of the preparation." Loc. cit., p. 144.

[2] Loc. cit., p. 178.

[3] Loc. cit., p. 156.

Many experiments on the influence of radioactive matter on plant growth have also been made by Stoklasa.[1] In one set of experiments there was observed the effect of adding varying amounts of uranium in the form of uranium nitrate to a given quantity of soil. Using plants of clover (*Melilotus albus*) a maximum increase in growth of 24 per cent was obtained when 1 part of uranium was used to 1,310,000 parts of soil. But the presence of lead in the form of lead nitrate was found to be even more stimulating in its action since a corresponding increase in growth was obtained with a concentration only one-eighth as great as the quantity of uranium which gave best results. Lead, however, is a rayless element and the effects observed with it must have therefore been due to its chemical properties. As a soluble salt of uranium had to be used to give the effects observed, it is reasonable to conclude that these effects are likewise due, in a large measure at least, to the chemical properties of the uranium rather than to its radioactive properties. Further evidence of the truth of this statement will be given later.

In other experiments Stoklasa[2] made a study of the change in rate of nitrogen fixation brought about by bacteria (*azotobacter chroococcum*) when cultures of these bacteria were placed in an atmosphere containing radium emanation. In carrying out the experiments 2 liters of air having an activity of 150 Mache units[3] were passed daily into the vessel containing the cultures and there resulted from this treatment a marked increase in the amount of nitrogen fixed by the bacteria. It was further observed that the time of germination of seeds was shortened and an increase in the development of plants resulted when watered with water having an activity of from 30 to 2,000 Mache units.

Using a concentration of emanation about 30 times as great as that given by Stoklasa, Fabre[4] likewise observed favorable results in the germination and growth of seedlings. Many experiments on the influence of radioactive matter on plants have also been made by other investigators, but unlike the results just cited the effects reported in the majority of cases were deleterious rather than beneficial.

As radium emanation is an inert gas, the results obtained with its use can not be due to its chemical properties, as in the case of uranium, but must be attributed to its property of being radioactive. It is thus necessary to conclude that radioactive material does have an effect on plant growth, and that when a certain concentration,

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[1] Compt. rend., **155**, 1096 (1912); **156**, 153 (1913); **157**, 879, 1082 (1913).

[2] Loc. cit.

[3] The unit now generally used for expressing a quantity of radium emanation is called the *curie*, or the *microcurie*, and is the amount of emanation in equilibrium with 1 gram, or 1 microgram, of radium. One microcurie per liter equals a concentration of about 2,700 Mache units.

[4] Compt. rend. soc. biol., **70**, 187 (1911).

but not too great a concentration, is used stimulating effects are to be expected in some cases at least. In fact it is to be expected, although not yet clearly demonstrated, that in greenhouse practice and in botanical research, where the results obtained might justify the expense involved, the radio-elements may prove of very great value, as they have done in other branches of science. When consideration, however, is taken of the scarcity of these elements, it does not follow from any experiment so far described that such elements can have any practical application as a fertilizer in general farming. To increase the activity of the atmosphere above the soil with radium emanation would not be feasible in field practice, neither would it be practical to add such a quantity of radioactive material to the soil that the emanation in the underground air would be increased to even the very low concentration used in Stoklasa's experiments, and the same may be said with regard to making irrigating water radioactive.

COMPOSITION OF RADIOACTIVE MANURE.

The source of the so-called radioactive manures consists of the residual rock from which carnotite or other uranium ores have been extracted; or of uranium ores which contain too low a percentage of uranium to make it profitable to extract the radium. Since an ore containing as low as 2 per cent of uranium oxide can be profitably used in the manufacture of radium, it is not to be expected that this percentage of uranium, or its equivalent of radium, will be found in any radioactive manure.

In the following table is given the composition of samples of radioactive materials which have been applied as a manure.

Analyses of samples of radioactive manure.

Constituent.	A	B	Constituent.	A	B
Silica (SiO_2)	80.44	85.90	Phosphoric anhydride (P_2O_5)		Trace.
Oxide of iron and alumina ($Fe_2O_3+Al_2O_3$)	2.20	8.65	"Soluble phosphoric acid"	1.37	
Lime (CaO)		.91	"Water, volatile organic matter"	10.54	0.93
Magnesia (MgO)		.95	"Soluble salts, soluble free acids"	3.32	
Soda (Na_2O)		.50	Uranium (U)	Trace.	1.00
Potash (K_2O)		1.04	Activity	.03 U	.037U
Sulphide (S)		.16			
"Sulphuric acid"	5.40				

A. Radioactive manure. Analysis according to Foulkes, Bul. Bureau Agricultural Intelligence and of Plant Diseases, 3, 1112. This apparently represents ore from which the uranium has been extracted. The acidity of the material was equivalent to 65 grams of sulphuric acid per kilogram.

B. Radioactive manure. Analysis by author. This material represented the original ore and therefore did not contain any free acid.

FIELD TESTS WITH RADIOACTIVE MANURE.

Field tests with radioactive manure (A in table) have been made by Foulkes[1] in England. The material used contained only a trace of uranium, but had an activity equal to 0.03 times that of uranium.

[1] Bul. Bureau of Agricultural Intelligence and of Plant Diseases, 3, 1111 (1912).

This was mixed with commercial fertilizers in the following proportions: Steamed bone, 20 parts; superphosphate, 15 parts; kainit, 10 parts; nitrate of soda, 5 parts; and radioactive manure, 1 part. One plot received an application of this mixture at the rate of 1,020 pounds per acre, and an adjoining plot received the same application, but without the radioactive manure. Both plots were planted to turnips, and when the crop was grown it was found that the yield was greatest in the plot to which the complete fertilizer, plus the radioactive manure, had been added. A similar result was obtained with mangels.

Radioactive material of exactly the same composition as that given by Foulkes was also used by Malpeaux[1] in making pot and field experiments with oats, potatoes, sugar beets, and mangels. The material was mixed with a complete fertilizer made up of sodium nitrate, superphosphate, and potassium sulphate to the extent of 5 per cent and applied at the rate of 22 to 44 pounds per acre. In the case of oats, sugar beets, and mangels, an increased yield of about 15 per cent was obtained on an average on the plots to which complete fertilizer, plus radioactive material, was added, over that obtained from the plots to which complete fertilizer only was added. In the case of potatoes, it was not observed that the radioactive material had any beneficial effect.

A very extensive series of experiments was also carried out by Berthault, Bretigniere, and Berthault,[2] using material for which exactly the same analysis was given as for the radioactive manure used by Foulkes and by Malpeaux. Its effect on a large number of crops (cereals, grasses, and roots) was tested by applying the material alone and when mixed with standard fertilizers. It was found that when the radioactive manure was used alone the positive and negative results were about equal for the total weight of the plants and for stalks and grain, but the negative results were the more numerous for tubers; with superphosphate the results obtained were generally unfavorable, particularly for the grain, but for tubers they were more often favorable; and with complete fertilizer the favorable results were the more numerous for all crops.

It was concluded that while the results obtained were not decisive, they show that radioactive substances were more efficacious in the presence of a complete fertilizer than when used alone, or with phosphate or nitrogenous manures.

It is difficult, however, to understand how this conclusion regarding radioactive substances follows from the experiments described by the authors, in view of the fact that they acknowledge having had the material which they used tested for radioactivity and that none could be detected. It therefore follows that the results obtained,

[1] Vie Agr. et Rurale, 2, 241 (1913). [2] Ann. Ecole Nat. Agr. Grignon, 3, 1 (1912).

whether of a favorable or unfavorable nature, could not have been due to the radioactivity of the material, but to some other influence.

As shown in the table, the acidity of the material was equivalent to 65 grams of sulphuric acid per kilogram, while the "soluble phosphoric acid" amounted to 1.37 per cent, and the "soluble salts, soluble free acids" amounted to 3.32 per cent. All these constituents when exceeding a certain minimum concentration have a marked effect on plant growth. Notwithstanding this, however, apparently no account was taken of the presence of these constituents in any of the foregoing experiments, but rather all effects observed, whether of a stimulating or retarding nature, were attributed to the exceedingly weak radioactivity of the material, which was claimed to be equal to 0.03 of the activity of uranium, but which at least in the case of the material used by Berthault, Bretigniere, and Berthault, was too small to be detected.

If it is assumed that the material used in these investigations has the radioactivity which was claimed for it, and that this was due to radium and its products, then it can be calculated that in an application of 25 pounds of the material per acre the amount of radium thus applied to an acre would be less than one one-hundredth of the radium already present on an average in an acre-foot of soil. This amount is so small that when uniformly distributed through the first 6 inches of the soil there would be radiated per second from the material added only about 2 alpha particles—that is, 2 atoms—from each pound of soil. Furthermore, of the particles so radiated, only a very small fraction would be able to escape from the particles of material in which they originate. The number of beta particles radiated would be still less than the alpha particles.

The radioactive material (B), of which an analysis is given in the table and which was kindly supplied by a firm in this country, has an activity of 0.037 that of uranium, and is therefore slightly more active than the material referred to above. An application of from 20 to 25 pounds per acre was recommended, mixed with some standard fertilizer, but even in the case where the largest application is used the quantity of radium so applied per acre is only one-fiftieth of the radium already present in an acre-foot of soil. In defense of the use of such a minute quantity of any substance it has been explained that "this material is not a fertilizer, but that it gives to the plant additional power to consume the plant food that is already in the ground or that is put there by artificial means in the form of any brand of fertilizer." The use of the word fertilizer in this statement is no doubt intended to mean a plant food. As already pointed out, however, a material does not necessarily have to act as a plant food to be properly called a fertilizer, for this term is also used with

reference to any material which when added to the soil brings about an increase in the growth of crops. If radioactive manure really acts in the way described, it could then be properly called a fertilizer; and, further, if its function is to give to the plant additional power to consume plant food, its effect should be noticed when added to the soil alone as well as when mixed with a standard fertilizer.

Field tests with radioactive mineral from still another source have been made by Ewart,[1] Melbourne University. These tests were made in two different places, in each of which there were selected a series of four plots. In the case of the first series each plot had an area of one-third acre. Plot 1 received 50 pounds of superphosphate per acre; plot 2, 50 pounds of superphosphate and 50 pounds of finely ground radioactive mineral per acre; plot 3, 50 pounds of radioactive mineral per acre; and plot 4 was unmanured. The plots used in the second series had an area of approximately one-fourth acre, and the same applications were made in this case as in the first, with the exception that 59-pound portions of the materials were used instead of 50-pound portions. From the yields obtained it was concluded that "there is no evidence to indicate any beneficial action of the radioactive mineral upon the growth and germination of wheat, when quantities which could be used in agricultural practice are employed. Any stimulating action which it might exercise when first applied, seems, if anything, to be converted into an injurious action when in prolonged contact. There is nothing, therefore, in these results to show that radioactive mineral is of the least benefit to wheat when applied in the same manner as manure."

CATALYTIC FERTILIZERS.

In addition to the experiments which have been described on the use of the radio-elements as fertilizers, many tests have also been made during the last few years of the action on plants of still other elements which are not recognized as essential to the growth of plants. Among the different elements which have been studied in this way may be mentioned copper, nickel, zinc, and lead. These elements are of rare occurrence in the soil, and are ordinarily recognized as plant poisons, but quite remarkable benefits have been obtained by the application to the soil of a very small quantity of a soluble salt of these elements. Plants so treated are said to have been stimulated, and because of the small amount of the material necessary to produce noticeable results, these compounds when used in this way are spoken of as "catalytic fertilizers."

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[1] J. Dept. Agr., Victoria, 10, 417 (1912).

With a concentration of 1 part of lead, as lead nitrate, in 965,000 parts of soil Stoklasa[1] obtained in pot tests with oats (*Avena sativa*) a maximum increase in growth for the grain and straw of 53 per cent over that which took place in the control pot; but on increasing the concentration of the lead only 2.5 times its toxic action became apparent, and a decrease in growth resulted. Similar results were also obtained, as already pointed out, in pot tests with clover using uranium nitrate. With this compound the maximum stimulation was obtained with a concentration of 1 part of uranium in 1,310,000 parts of soil, but as the concentration of the uranium was increased its toxic action became manifest, and the crop yield gradually decreased.

A corresponding series of experiments was also made by Loew and his coworkers[2] using salts of both uranium and thorium. From the results obtained it was concluded that "uranium and thorium compounds differ widely in their effects on plants, uranium salts being highly poisonous, thorium salts not."[3] It is known that thorium and uranium both give off the same rays and of approximately the same intensity. It would be expected, therefore, if the effects which these elements produce on plants are due to their radioactivity, that the effects would be approximately the same for each element. Since this is not the case, and since the results obtained with uranium correspond with those which follow the use of the so-called catalytic fertilizers, it is necessary to conclude that the action of uranium on plants is due to its chemical properties rather than to its property of being radioactive.

The material (B) of which an analysis is given in the table above contains 1 per cent of uranium oxide. An application of this material of about 175 pounds per acre would thus give to the first six inches of the soil a concentration of uranium equal to that which Stoklasa found, in the form of the nitrate, gave greatest stimulation to clover plants. An effect would, therefore, be expected to follow the addition to the soil of finely ground uranium ores, but whether the result will be beneficial or otherwise will depend on the amount applied and the kind of crops grown.

In the various experiments which have been described on the use of radioactive manure no account has apparently been taken of the chemical action of the uranium present, and the conflicting results obtained with radioactive material from different sources are no doubt to be explained by the fact that the radioactivity of the material was alone considered without regard to the presence or

[1] Compt. rend., 156, 153 (1913).
[2] Bul. Coll. Agr., Tokyo Imperial Univ., 5, 173 (1902) : 6, 144, 161 (1904).
[3] Ibid, 6, 165.

absence of uranium, or of such nonradioactive constituents as soluble salts and free acids.

The subject of catalytic fertilizers is an interesting one, and worthy of careful investigation, but the manner in which they are able to influence so effectively the growth of plants is as yet but little understood. Until further knowledge is gained along this line, and particularly until it is demonstrated that the application of such materials to the soil will not lead to their accumulation with injurious results, the use of uranium, or of any of the other heavy metals, as a fertilizer in general farming is not to be recommended.

SUMMARY.

Attention is called to a new material which has recently been exploited for use as a fertilizer, and which consists of the residual rock from which uranium has been removed, or of uranium-radium ores of too low grade to be used for the extraction of radium. This material, which is known as "radioactive manure," is claimed by virtue of its activity to have a marked effect on stimulating the growth of plants when mixed with a relatively large amount of standard fertilizers and applied at the rate of 20 to 50 pounds per acre.

When consideration, however, is taken of the facts: (1) That the greatest quantity of radium which can exist in an ore amounts to only 0.00003 per cent; (2) that the intensity of the radium rays is limited by the quantity of radium present; (3) that all rays, like all chemical substances, must exceed in intensity or concentration, a certain limiting value to produce any noticeable results, or any results whatever; (4) that radium costs $120,000 a gram; and (5) that the activity of radium or any other radio-element can not be increased by any treatment whatsoever, but remains unchanged in whatever state of combination it may exist, it seems incredible that radium or any of its products can have any economical application as a fertilizer in general farming; and still less credible that the so-called radioactive manure has any value, as far as its radioactivity is concerned, since the radium already present, on an average, in an acre-foot of soil, is about 100 times greater than is contained in the quantity of radioactive manure commonly recommended for application to an acre.

Many experiments have been made in studying the influence of the radio-elements, when freed from their ores, on the germination of seeds and the growth of plants, and from the results obtained it is to be expected that in botanical research, and possibly in greenhouse practice, where the results obtained may justify the expense involved, the radio-elements may prove of considerable value; but when consideration is taken of the scarcity of these elements it does not follow

from any experiments yet described that such elements can have any practical application as a fertilizer in general farming.

Evidence is given to show that the action of uranium on plants is due to its chemical properties rather than to its property of being radioactive, and that the conflicting results obtained with radioactive manure from different sources is to be explained largely by the presence of uranium, and of such nonradioactive constituents as soluble salts and free acids.

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